AN ANALYSIS OF THE REDUCTION IN REACTION TIME AND OF THE EFFECT OF SEAT TILT IN A SINGLE-PEDAL AUTOMOTIVE SYSTEM

by

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THESIS

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Captain, United States Marine Corps
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ABSTRACT

A total of 55 test subjects from age 14 to age 79 contributed 4400 recorded reaction times in a controlled experiment in the Human Factors Laboratory of the Operations Research Department at the Naval Postgraduate School. One purpose of the experiment was to compare the conventional brake and accelerator system to a new, dual-function, single-pedal system that was developed at the school. A second purpose was to investigate the effect on reaction time of a five degree seat tilt at pedal-floor angles of 45, 50, and 55 degrees with this new pedal.

The average reaction time saved by the single-pedal system was more than 44 percent. The average reaction time on the conventional two-pedal system was 0.46820 seconds compared to 0.25919 seconds for the new one-pedal system. Seat tilt affected reaction time only at the 45 degree angle.

In terms of distance, a savings of 0.20901 seconds for a vehicle traveling at 60 MPH represents a saved distance of 18.39 feet, or about one car length. This margin of safety is not currently available in commercial or military vehicles.

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The development of a research project for a thesis is a challenging and complicated task. The problems diminish when the experimenter meets enthusiastic, responsible people who expend their time and energy generously and patiently.

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I. INTRODUCTION

In the United States the number of motor vehicles on the nation's roads, streets and highways has been growing faster than the number of people. The number of miles traveled in automobiles each year establishes a new record annually. The impact of these facts is that there will be greater accident potential, resulting in new records annually in deaths, injuries, and costs due to accidents. The need for increased safety is apparent in this man-machine system that has become a vital part of the American way of life.

Since World War II, the number of autos, trucks and buses has grown from 30 million in 1945 to 103 million in 1970. Over this same time span, the population of the United States has risen by 46 percent. (U. S. News and World Report, 25 May 1970).

Motor vehicle travel in the United States tripled in the past 30 years. According to the U. S. Bureau of Public Roads, the number of miles traveled in motor vehicles in one year exceeded one trillion miles in 1968.

In a country that is not yet 200 years old, many enemies have been met and subdued. However the motor vehicle, a man-machine system less than a third of the age of the country, has killed and injured more Americans than all the wars we have ever fought. Increased safety programs and devices have not yet subdued this national enemy.

The National Safety Council has released data on accident facts that are grim. Nearly 5 million men, women, and children are killed or injured each year in motor vehicle accidents. Of 26 million drivers, nearly one driver in four is involved in an accident. In over 14 million

accidents, the value of property destroyed and damaged was estimated at 4 billion dollars. The chief cause of at least 80 percent of these accidents is driver error due to speed. (Accident facts, 1969).

An analysis of the data provided by the National Safety Council revealed accident facts by age groups. Approximately 20 percent of all drivers are under age 24, yet these drivers have over 33 percent of all motor vehicle accidents. In both fatal and non-fatal accidents, young drivers have a significantly higher frequency rate than other drivers. Drivers age 70 or older do not have an unusual number of non-fatal accidents, but they have a highly significant frequency of fatal accidents.

Drivers of all ages and occupations become involved in motor vehicle accidents for many reasons but the primary factor is operator error due to excessive speed. One approach to automotive safety is to concentrate on this vital area of speed, that is distance per unit of time. A margin of safety can be obtained by reducing the reaction time of drivers in braking a motor vehicle. A dual-function pedal is one device in the man-machine system that reduces the human time lag when danger is imminent.

This research concentrates on reaction time reduction by using a single-pedal, dual-function pedal in an automotive braking system. The reaction time of the operator is the time between the appearance of a danger signal or stimulus and the start of the braking process by the machine. Using time in seconds as a measure of effectiveness, the amount of reaction time reduced and the effect of seat tilt were two problem areas that were analyzed for the purpose of increased safety in motor vehicles.

II. THE LITERATURE

The motor vehicle as a man-machine system required good operator coordination when the controls included a manual gear shift with clutch, brake and accelerator pedals. Research efforts involved both single-function and dual-function pedals even before the introduction of the automatic transmission. When this advance in technology occurred, the three-pedal system gave way to the two-pedal system in most automobiles.

Operators easily adjusted to this new system of accelerating and braking with an automatic transmission. To the relief of the driver, the required tasks were reduced for the hands and the left foot was free with no required task. Inevitably, some attempts were made to brake with the left foot and to accelerate with the right foot. Researchers and designers experimented with this technique, but also continued to search for optimal designs for both single-function and dual-function pedals.

The first efforts to determine the optimal design of a single-function pedal were made by Barnes and others (1942). They investigated five pedals with different fulcrum locations. Twelve male and three female subjects performed a routine twice, first using the pedals in numerical order and then reverse order. The routine consisted of rapidly moving a foot pedal up and down for 90 seconds. The best pedal had the fulcrum at the heel and a downward stroke travel time of 0.109 seconds. The worst pedal had a downward time of 0.137 seconds.

Trumbo and Schneider (1963) presented their studies on the man-machine aspects of a foot pedal. They were concerned with the number of times that subjects could depress and release different pedals in a

short time interval. The most useful and less fatiguing pedal design placed the fulcrum under the heel. This meant only the toe performed the downward movement of the pedal. Their criterion was number of responses per minute.

Ayoub and Trombley (1967) also concluded that the optimal position for the fulcrum is at the heel when a load is attached to the ball of the foot. Using five test subjects, they measured reaction time to a light stimulus and travel time to move a pedal to a fixed stop.

Morgan and others (1963) stated that when a pedal with greater than 20 pounds of pressure is to be moved, the movement force should be applied along the long axis of the lower leg. When smaller movement forces but continuous operation are required, the movement force should be applied mainly from the ankle.

McFarland and others (1966) suggested that the angle between the long axes of the foot and the lower leg should be 90 degrees when holding the foot in position for pedal pressures under 20 pounds. For these light pedal pressures, the knee angle should be greater than 90 degrees, with 135 degrees or more preferred.

Belzer (1965) focused on the use of the left foot for braking and the right foot for accelerating. He stated that the left foot will be faster than the right only when the left foot is poised on the brake pedal. Belzer observed that the operator had a tendency to leave the right foot on the accelerator when using left-foot braking. This reduced part of the braking effect.

Dual-function brake pedal designs have existed since the early 1920's. The United States Patent Office has more than 16 patents of various dual-action brake pedal mechanisms, including a recent design stemming from research at Kansas State University.

White (1963) installed both the conventional and combined brake-accelerator pedal in an automobile. He could select either brake pedal while testing five subjects. The results indicated the combined brake-accelerator pedal was 0.115 to 0.150 seconds faster than the conventional brake pedal. However, the test subjects caught the sole of their shoe on several occasions while using the conventional pedal for an emergency stop. This increased the average stopping distance by 81 feet.

Humphrey, Incorporated (1968) developed a "one-pedal control" of a car. The braking function is accomplished by lifting the foot from the accelerator pedal. An upper proportional braking zone, a middle neutral or coasting zone, and a lower acceleration zone provide three distinct braking zones in this system. The operator has to keep his foot constantly on the pedal. If the foot is raised from the pedal due to fatigue or some other reason, the vehicle would come to a sudden stop.

There has been extensive research accomplished in the Department of Industrial Engineering at Kansas State University (KSU). To date there have been nine experiments completed in a three year period. Experiments one, two and three have been described by Konz and Daccarett (1967). Experiments four, five and six have been described by Konz and others (1968). Experiment seven, eight and nine were individual M.S. theses by Wadehra (1968), Sathaye (1969) and Chawla (1969) respectively.

Experiment one compared the performance time of hand and foot control activation for twelve subjects in four test conditions. The critical factor in reducing reaction time was movement time. For foot controls, braking reaction time was 0.590 seconds when the right foot was used in the conventional, two-pedal system. When the left foot was on the brake pedal and the right foot was on the accelerator in the conventional

system, the average time was 0.390 seconds. Reaction time was reduced 33 percent by left foot braking when the left foot did not have to move from the floor to the brake pedal.

Experiment two at KSU consisted of testing 121 subjects with a combined brake-accelerator pedal designed by Winkleman. This dual-function pedal, (U. S. patent number 2,878,908), performed acceleration by toe depression and braking by heel depression. An interlock prevented simultaneous operation. The average reaction time was 0.42 seconds. Males, two-thirds of the subjects, had an average of 0.41 seconds compared to the female average of 0.44 seconds.

In experiment three, the Winkleman one-pedal system was compared with a three-pedal system consisting of clutch, brake and accelerator in an American Automobile Association (AAA) device. Subjects were 25 faculty and student volunteers. The three treatments were left foot on brake pedal while right foot on accelerator, right foot accelerating and braking on separate pedals, and right foot operating the dual-function, single pedal. Average reaction times were 0.290 seconds, 0.450 seconds, and 0.360 seconds respectively.

Experiment four was a road test in a 1960 automobile equipped with an automatic transmission. The dual-function pedal and the two conventional pedals provided two treatments for 16 subjects who drove two miles with each system. Average reaction time was reduced from 0.57 to 0.47 seconds.

Experiment five at KSU took place in the laboratory with a new, dual-function pedal designed by Koe without an interlock. The difference between the Winkleman and Koe pedals was this interlock, which prevented simultaneous actuation of the brake and accelerator. Seventy-two subjects

experienced three treatments: the AAA three-pedal system, the 1960 automobile two-pedal system, and the new one-pedal system. Average reaction times were 0.482 seconds, 0.435 seconds, and 0.323 seconds respectively.

In experiment six, the distances from the heel of the pedal to the accelerator and brake shafts were varied on the dual-function pedal designed by Koe. Eleven males and five females served as paid subjects. The criterion was minimum reaction time. No combination of pedal-shaft distance was found better than another.

Experiment seven, conducted by Wadehra (1968), was an investigation of the effect on reaction time of the angle between the pedal and floor, of the force on the accelerator shaft, of the force on the brake shaft, and of the seat reference distance (SRD). SRD is the horizontal distance between the heel of the pedal and the intersection of the back and bottom seat surfaces. Minimum time for this single-pedal system was 0.241 seconds. Brake and accelerator force had little effect on reaction time. Wadshra recommended an accelerator force of 4 to 8 pounds, a brake force of 13 to 21 pounds, a pedal-floor angle of 40 to 50 degrees, and a seat reference distance of 45 to 55 percent of a subject's height. Wadehra, who used four, male, paid subjects whose average age was 23, found some learning effect present in his results.

Experiment eight at KSU was conducted by Sathaye (1969), who also used four paid subjects whose average age was 23 years. The test subjects were timed in a 1956 automobile whose engine was running, but whose rear wheels were above the pavement. The car was modified with a different seat and with the dual-function pedal. Sathaye recommended a pedal-floor angle of 30 to 45 degrees, a seat height 8 to 10 inches above the floor, a clockwise twist on the pedal of 0 to 14 degrees, and a seat reference

distance of 40 to 50 percent of a person's height. The minimum reaction time was 0.284 seconds.

Experiment nine was the most recent research completed at KSU. Chawla (1969) used four staff members whose average age was 60 years. One was a female subject. All were tested in the 1956 automobile with motor running and rear wheels above the pavement. Chawla recommended a pedal-floor angle of 30 to 40 degrees, a seat reference distance of 45 to 50 percent of a person's height, and a clockwise twist on the pedal of 0 to 15 degrees. A counterclockwise twist on the pedal increased reaction time. The reaction time of the optimum combination was 0.270 seconds.

Chawla also analyzed the data obtained from 50 Engineering Open House visitors on March 15, 1969, at KSU. For each of these 40 male and 10 female subjects, twelve reaction times on the three-pedal, AAA, brake-accelerator system and twelve reaction times on the one-pedal, dual-function system were taken. The highest and lowest times were eliminated. No practice was allowed. The average age was 30 years for subjects from age 16 to age 67 years of age. The average reaction time for all subjects on the three-pedal system was 0.470 seconds and on the one-pedal system was 0.280 seconds. The average time saved of 191 milliseconds reduced reaction time by 39.6 percent.

At the Naval Postgraduate School (NPS), two combined brake-accelerator pedals were designed by Dr. G. K. Poock, A. E. West, and T. J. Toben. One pedal was hinged three inches from the heel but the other pedal was unhinged. Both pedals were 12 inches long and 3.5 inches wide. When the toe of each pedal was depressed, a shaft actuated acceleration. Braking was accomplished by a shaft depressed by the heel.

In experiment one at NPS, West (1969) tested 48 male subjects in the Human Factors Laboratory. Pedal-floor angles were 45 and 60 degrees. There was no twist angle on the pedals. Seat reference distance was fixed at 50 percent of the subject's height. At the 45 degree angle, the solid pedal allowed faster reaction times than the hinged pedal. There was no statistically significant difference between the two pedals at the 60 degree angle. The minimum average reaction time was 0.222 seconds with the solid pedal at the 60 degree floor angle. This average time, based on four recorded times after practice trials, was slightly faster than the minimum time obtained at KSU by Wadehra (1969), which was 0.241 seconds.

Experiment two at NPS was conducted by Toben (1970) who tested 36 unpaid subjects using the solid pedal. The ages of these male, military personnel ranged from 18 to 52 years. The dual-function, single pedal was tested at pedal-floor angles of 45, 55 and 65 degrees. The pedal-twist angles, or clockwise-rotational angles, were 0, 15 and 30 degrees. The seat reference distance was adjusted by the test subject. The minimum reaction time was 0.286 seconds at the 55 degree floor angle and zero degree rotation. This time was based on four recorded times for each person at each of the nine positions of the single pedal. The combination of 55 degree floor and 15 degree rotational angles had essentially the same effect on reaction time as the 55/0 degree combination, but these two treatments were significantly better than the other seven combinations.

Up to this time, no direct comparison had been made between the two-pedal, conventional system and the solid, one-pedal system at NPS.

III. THE PROBLEM

This experiment focused on three aspects of the single-pedal system. First, the motivation of subjects to perform the treatments without monetary compensation; second, the amount of reaction time saved by using the single pedal designed at the Naval Postgraduate School; and finally, the effect of seat tilt on reaction time in the single-pedal system.

At Kansas State University, Wadehra paid four male subjects in Experiment Seven. Sathaye paid four subjects in Experiment Eight.

In Experiment Two at the Naval Postgraduate School, Toben used enlisted men for age group 18 to 24 years. They were not paid for their participation and their performance was the worst of four age groups. Toben suggested the motivation factor as a probable cause.

This experimenter felt that motivation could be attained without a monetary incentive by an appeal to the curiosity of the test subjects and by an application of salesmanship. The method would also affect the second area of concern, the amount of reaction time reduced.

Before the test subjects started the experiment, they wanted to know what their reaction time was in a two-pedal system and how much their reaction time was reduced by a one-pedal system.

The use of an American Automobile Association (AAA) device with the Naval Postgraduate School (NPS) apparatus provided a means of comparison that satisfied the curiosity of the test subjects. While still enthusiastic, the same subjects continued with the seat-tilt portion of the experiment.

Most automobiles have a slight seat tilt. When a driver adjusts the seat, the seat is higher when pulled forward than it is when pushed

backward. This is designed to accommodate both short and tall drivers for a fixed seat height and a fixed pedal angle.

This experimenter investigated the effect of a seat tilt of five degrees on reaction time in the NPS, one-pedal system. A comparison of a seat that was level would be made with a seat that was tilted five degrees above the horizontal plane at the front edge of the seat.

In the investigation of seat tilts on reaction time, the pedal angle with the floor would be varied. The test subject would vary the seat reference distance (SRD) by adjusting the seat until comfortable. The seat height and the angle of twist, or rotation angle, on the pedal would remain fixed. In this portion of the experiment, the problem addressed was the effect of seat tilt on reaction time at one of three floor angles.

IV. THE EXPERIMENT

A. APPARATUS

The comparison between the two-pedal system and the one-pedal system was accomplished by using two separate test "vehicles". The two-pedal system was an American Automobile Association (AAA) device that contained a steering wheel, a dashpanel with signal lights, and separate brake and accelerator pedals. This AAA device was placed on a heavy rubber mat six feet in length. An ordinary aluminum chair was the seat in this test "vehicle," which will be referred to as the AAA system. See figure 1.

The one-pedal system was a test "vehicle," with essentially the same components that were used by West (1969) and Toben (1970). There were several modifications. A 4.5 inch high, green, wooden platform 67 inches long and 37 inches wide formed a solid base on which the seat, steering wheel, and pedal assemblies were mounted. A sixty-watt, red light bulb was attached to a wooden panel 47 inches wide and 61 inches high. The red bulb was 41 inches above the floor. This panel was placed five feet in front of a seated test subject. The red light simulated a tail light of a large truck that was traveling at 60 MPH directly ahead of this test "vehicle". This apparatus will be referred to as the NPS system. See figure 2.

Test equipment included an electronic control box for each system, an audio oscillator and an electronic counter. The control boxes had indicator lights and silent switches. See figure 3. The audio oscillator generated a 1000 cycle-per-second signal that was sent to the electronic counter whenever the control switch activated the red signal

Figure 1. The Two-Pedal Test "Vehicle".

Figure 2. The One-Pedal Test "Vehicle".

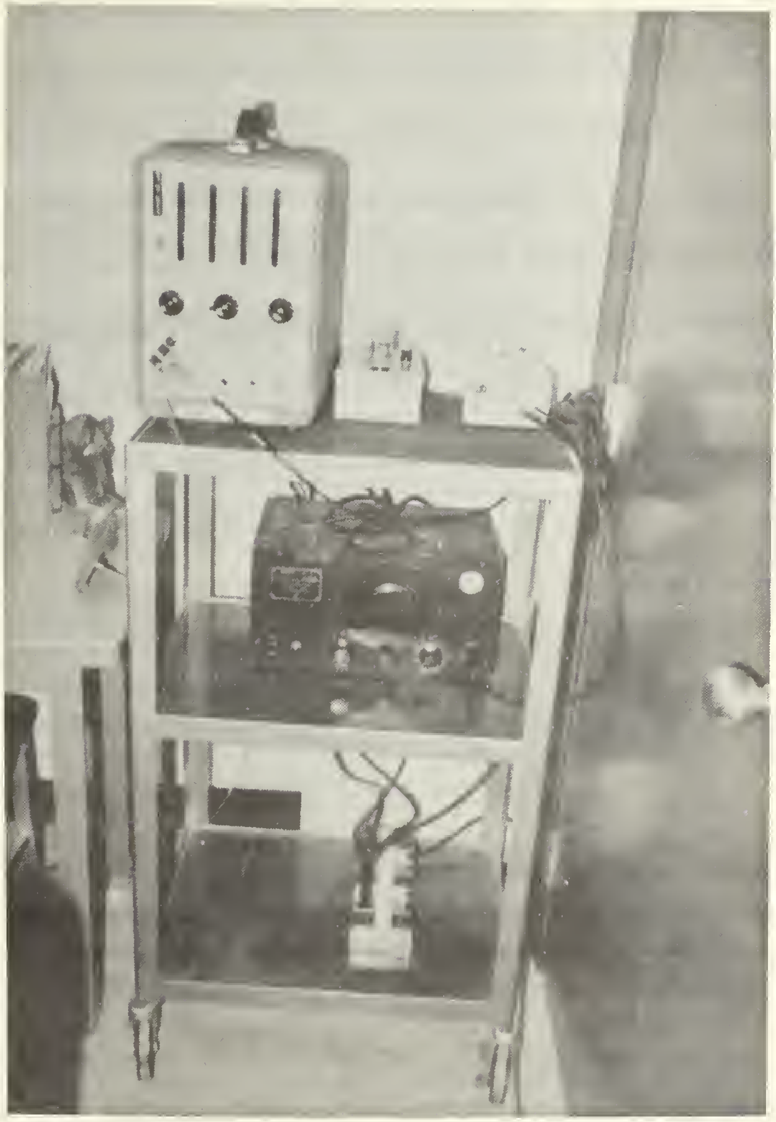

Figure 3. The test equipment that was used to record reaction times for both the one-pedal and the two-pedal systems.

light in either system. When the brake-pedal shaft was depressed one-sixteenth of an inch, a micro switch interrupted the circuits for the red light signal and the audio signal to the counter. The reading on the counter was elapsed time in thousandths of a second.

The AAA system was a complex reaction time device, 1958 model, designed by the Traffic Engineering and Safety Department of the American Automobile Association. The accelerator pedal was 2.5 inches wide, 9 inches long, and fixed at 60 degrees above the horizontal. There was no twist angle on the accelerator pedal. It was parallel to the direction the test subject was facing. The accelerator pedal could be depressed 2.5 inches.

The brake pedal in the two-pedal, AAA system was 3 inches wide, 2 inches high, and could be depressed 5 inches. However, the electrical circuit was opened when the brake shaft was depressed one-sixteenth of an inch. The brake pedal was positioned so that there was 1.5 inches between the right edge of the brake pedal and the left edge of the accelerator pedal. See figure 4.

In the NPS system, the pedal was the solid pedal recommended by West and also used by Toben. It was 3.5 inches wide and 12 inches long. The brake shaft was 1.75 inches from the rear edge of the pedal. The accelerator shaft was 3 inches from the front edge of the pedal, which meant that there was 7.25 inches between the two shafts. The pedal was made of aluminum and had a rubber strip on the top surface to prevent shoe slippage. A half-inch, metal strip one inch from the rear of the pedal supported the shoe heel of the test subject. The half-inch metal strip along the right edge of the pedal used during Toben's experiment was removed.

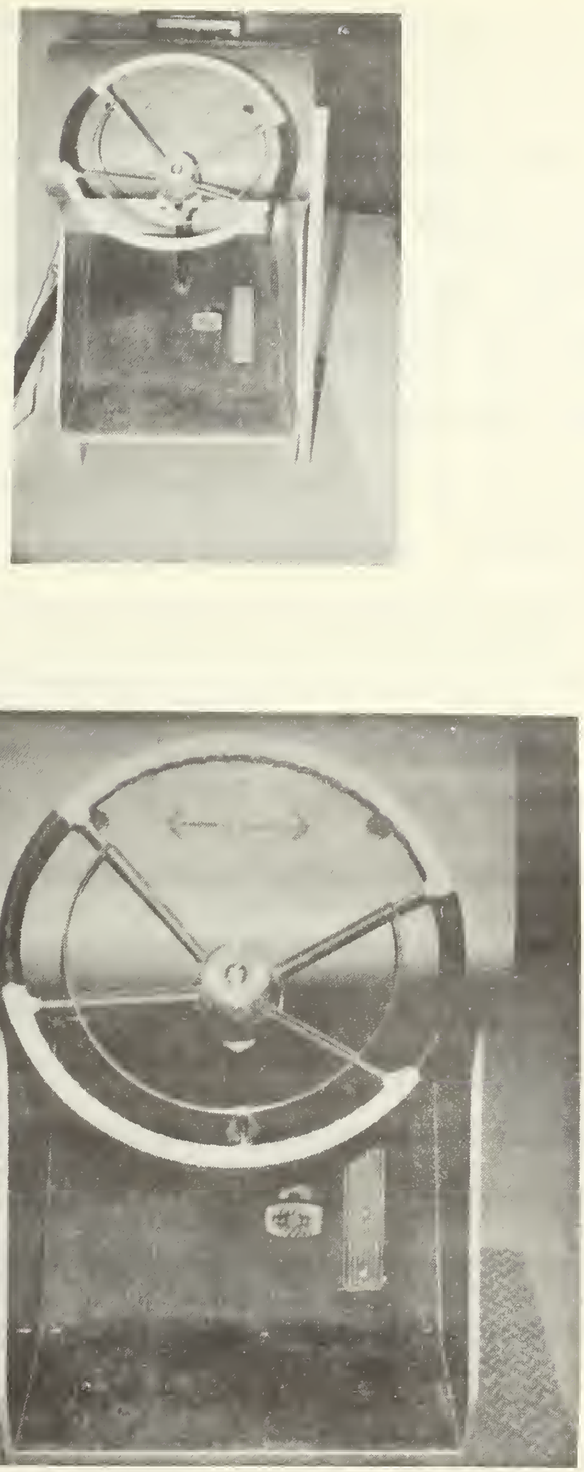

Figure 4. Views of the two-pedal, AAA system.

This single pedal that performed two functions was attached to a 6" x 14" x 1/4" aluminum plate. This plate supported two micro switches under the brake shaft and a linear potentiometer with a relay switch under the accelerator shaft. The two micro switches were connected to circuitry that turned off the 60 watt, red signal light, and the electronic counter, and turned on a red lamp on the control box whenever the brake shaft was depressed. When the accelerator shaft was depressed, the linear potentiometer allowed current to flow in a D.C. circuit to a voltmeter which was simulating a speedometer. A white light on the control box was activated whenever the accelerator shaft closed the relay switch. See figure 5.

At Kansas State University, Sathaye found in experiment eight that an angle of twist on the pedal that varied from zero to fourteen degrees did not have a significant effect on reaction time. At NPS, Toben found no significant effect on reaction time when the pedal was rotated either not at all or fifteen degrees to the right of the driver's forward direction.

For this experiment the pedal angle of twist was zero for the direct comparison with the AAA device which had no rotation angle on the pedal. However, during the seat-tilt portion of the experiment, the angle of rotation on the pedal was fixed at ten degrees to the right of the driver's forward direction.

In the NPS system, the pedal assembly was mounted to a 1/4 inch aluminum plate 18 inches square. The vertical height of the heel of the pedal was 5.5 inches above the wooden platform. To compensate for uneven foot height, a metal step was welded to a black, 1/4 inch, aluminum plate also 18 inches square. This modification meant that a person's left foot was the same height as his right foot.

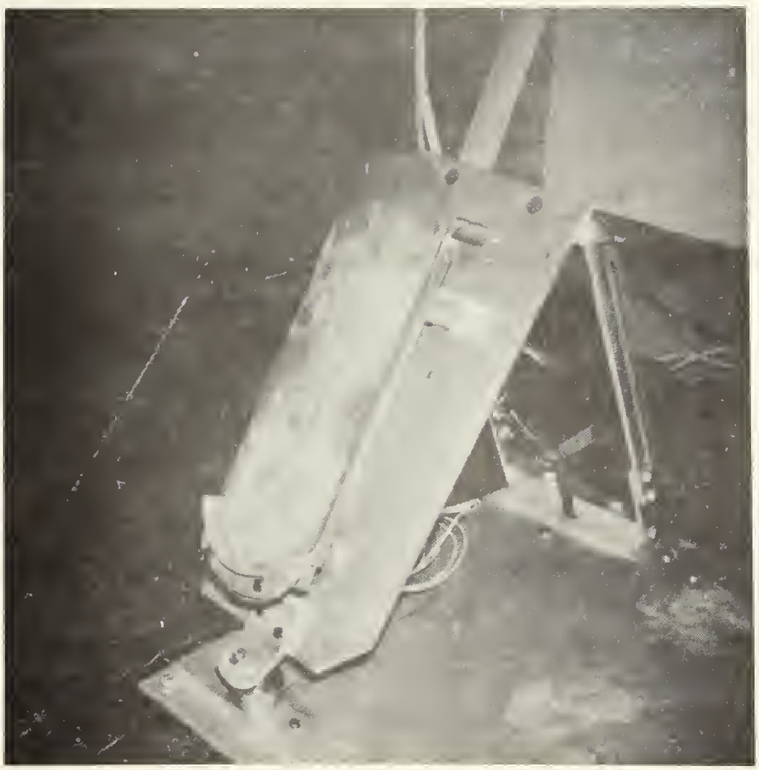

Figure 5. Views of the dual-function pedal.

A redesigned steering-wheel assembly was necessary in this experiment to allow sufficient leg room under the 17-inch-diameter steering wheel when the seat was tilted. This was accomplished by using telescoping metal pipes as vertical supports for a solid metal bar. A metal plate attached to this bar supported both the "speedometer" and the steering wheel shaft. The design was flexible so that the test subject could adjust the steering wheel in closeness, height and tilt.

The seat assembly in the NPS system was also redesigned to allow for a rapid change in seat tilt. The seat itself was the same seat used by both West and Toben. About 7 inches thick, the seat surface was 18 inches high, 18 inches long and 20 inches wide. The top edge of the back of the seat was five inches to the rear of a vertical line passing through the seat reference point. This 16 degree tilt was present when the seat tilt, in terms of the experiment, was "zero". See figure 6.

The seat reference point was 17 inches above the wooden platform. This meant that the vertical height of the seat above the pedal, a term called seat height, was 11.5 inches.

The seat runners were modified for better stability. In half-inch increments, the seat could be adjusted by the test subject for a range of six inches. This was one inch shorter than the seat runners used by both West and Toben, which had worn out.

By defining seat reference distance (SRD) as the horizontal distance between the seat reference point and the heel of the pedal, the SRD in this experiment ranged from 28.5 to 34.5 inches. This horizontal distance, when divided by a person's height in inches, provides a number whose value is approximately one half.

The four legs of the seat were attached to a hinged plate that could be tilted. The rear of this plate was anchored to the wooden platform

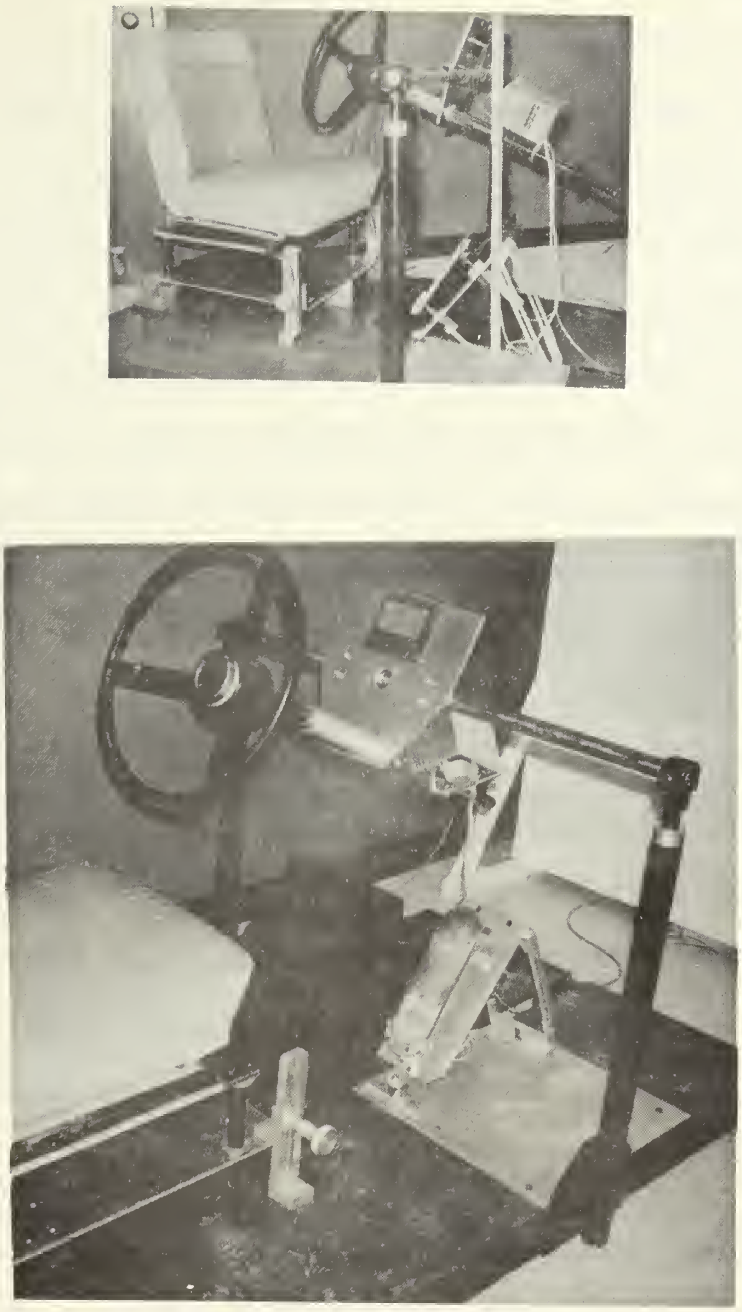

Figure 6. Views of the pedal, steering wheel, and seat assemblies of the one-pedal, NPS system.

that also supported the steering wheel and pedal assemblies. Inserted in machine-grooved, aluminum, vertical supports, quick release knobs with brass rings held the front edge of the seat base plate at any range of angles. The two angles selected for this experiment were zero tilt (seat base plate horizontal) and a five-degree tilt (seat base plate front edge five degrees above the horizontal plane). For ease of reference, "T0" will refer to a seat whose base plate is horizontal, while "T5" will refer to a seat whose base plate is raised five degrees above the horizontal at the front edge. This also means that the back of the seat is depressed 16 degrees at "T0" and 21 degrees at "T5" with respect to a vertical line passing through the seat reference point. See figure 7.

While the seat tilt was either zero or five degrees, the pedal-floor angle could vary. In the comparative portion of the experiment, the pedal angle was 60 degrees for both systems. In the seat-tilt portion, the pedal floor angles selected in the NPS system were 45, 50, and 55 degrees. The selection of these pedal angles as well as the rotation angle was based on Toben's recommendations.

B. ENVIRONMENT

The experiment took place in the Human Factors Laboratory of the Naval Postgraduate School. This windowless room is adjacent to other classrooms, all of which are air conditioned. Generally, there were no interruptions in the testing procedure, which usually lasted 30 minutes per subject.

The test subject's field of vision was restricted by wooden room dividers painted white, or by a wall. There was no background noise except for an occasional bell that signalled a class convened or ended.

Figure 7. A test subject on the NPS device with a 5 degree seat-tilt, a 50 degree pedal-floor angle, and a 10 degree rotational-angle on the dual-function pedal.

The test subject could not see the control boxes with the switch that would activate the experiment signal. This signal was a red bulb used to simulate the tail light of a large truck ahead of the test "vehicle".

C. SUBJECTS

The 55 male subjects who participated in this experiment were unpaid volunteers. There were 28 officers on active duty in the military of the Army, Navy or Marine Corps, three of whom were instructors at the Naval Postgraduate School. Of the 27 "civilian" subjects, 7 were professors, 7 were security guards, and 2 were retired military officers. The oldest subject was a retired Army Lieutenant-General who was 79. The remaining subjects had varied backgrounds with construction, machine and electronic skills. All of the participants had operated a three-pedal system, consisting of a clutch, brake, and accelerator, or a two-pedal system, consisting of a brake and accelerator. None of the test subjects had participated in a single-pedal system experiment previously.

Subjects were classified by age groups, primarily as a basis for comparison with results obtained by West and Toben. The age groups were 14-24, 25-30, 31-36, 37-52, and 53-79. There were 11 subjects per age group. The average age of all subjects was 37.

D. PROCEDURE

Each subject was randomly assigned a test sequence that determined the order in which each treatment would be experienced. The comparative portion always preceded the seat-tilt portion of the experiment. This means 28 subjects started with the two-pedal system, then switched to the one-pedal system and continued with the seat-tilt portion. The remaining 27 subjects, from all age groups, started with the NPS system,

continued with the AAA system and then proceeded with the six seat-tilt treatments, i.e., combinations of three floor angles and two seat-tilt angles. No sequence was repeated.

When the test subject entered the laboratory, he was shown all of the devices on display. The experimental procedure took about one minute of instruction. This satisfied his curiosity and enabled him to concentrate on the experimental tasks. He was informed of the fastest average time in his age group for the AAA system and the NPS system after he was told the purpose of the experiment.

Before each of the eight different treatments, the subject practiced the test procedure ten times. This amount of practice reduced the learning factor and provided the opportunity for final adjustments of seat position before the recorded test started. The time between signals varied between five and twenty seconds.

For each treatment, the subject depressed the accelerator to simulate traveling at 60 MPH. Then the subject focused his attention on the red light which simulated the tail light of a large truck traveling ahead of his vehicle at 60 MPH. When the truck tail light flashed on, the test subject had to jam on the brake in order to avoid a rear-end collision. The brake shaft tripped micro switches that turned off the red light and stopped the electronic counter. The elapsed time was recorded. This procedure was repeated ten times for each of the eight treatments.

On the AAA device, the red signal light was on the dashpanel. The accelerator was depressed to the floorboard. For the NPS system, the red signal light was larger but five feet in front of the subject. The accelerator was depressed so that the needle of the voltmeter (speedometer) was between two red lines depicting 60-65 miles per hour. This procedure insured a common initial position of the accelerator.

When the elapsed time was recorded, the counter had to be reset. This gave the test subject time to depress the accelerator and prepare for the next "panic" stop.

After each treatment, the apparatus was adjusted for the next treatment. The subject stood up between adjustments to reduce fatigue. In the seat-tilt portion, the subject also ranked the six treatments in terms of comfort. This involved talking to the experimenter who kept the conversation focused on the experiment.

When the experiment was completed, the experimenter computed the two average reaction times for the comparison of the two systems. This was done while the test subject recorded his age, height, weight, and years of driving experience. The amount of reaction time saved by the NPS system was explained in terms of distance. Most subjects were curious about their reaction time ranking in comparison to others who had taken the test. This entire procedure averaged about 30 minutes per subject.

V. DATA REDUCTION AND PROCESSING

When the 55 test subjects completed the experiment, the recorded data for each person included 80 reaction times, 8 seat reference distances (SRD), and the sequence in which the test subject experienced the 8 treatments. The eight treatments consisted of the AAA-NPS comparison plus six combinations of tilt-floor angles. There were six ranked treatments based on comfort in the seat-tilt portion of the experiment. In addition, each person provided his age, height, weight, and years of driving experience. Each test subject left the testing laboratory with his average reaction times on the AAA two-pedal system and on the NPS one-pedal system. He also knew his percentage of time saved by the one-pedal system.

In evaluating the information that 4400 recorded reaction times could reveal to the experimenter, the first consideration was the processing of ten recorded reaction times for the eight treatments experienced by each subject. The main emphasis was to reduce to a more manageable size the total items contributed by each person who participated in the experiment.

Since the 10 individual reaction times for each treatment were not considered as valuable as the average reaction time for each treatment, the first step in the data reduction process was the averaging of 80 data points for each subject. This yielded 8 average reaction times per person. These average reaction times were unbiased, maximum-likelihood estimators of the true mean reaction time for each person, for each treatment effect.

The information was tabulated by item or variable. The mean and the standard deviation of each variable was based on a sample size of 55. The results were:

VARIABLE	DESCRIPTION	MEAN	STANDARD DEVIATION
1	Age	37.7 years	15.77
2	Height	70.3 inches	3.10
3	Weight	174.6 pounds	22.95
4	Experience	20.1 years	14.28
5	AAA SRD	35.3 inches	1.80
6	NPS SRD	33.4 inches	1.41
7	TOF45 SRD	31.9 inches	1.67
8	TOF50 SRD	32.4 inches	1.73
9	TOF55 SRD	32.9 inches	1.58
10	T5F45 SRD	30.3 inches	1.50
11	T5F50 SRD	30.5 inches	1.72
12	T5F55 SRD	31.0 inches	1.58
13	AAA Score	0.46820 seconds	0.05
14	NPS Score	0.25919 seconds	0.03
15	D = AAA-NPS Score	0.20914 seconds	0.04
16	% = D/AAA Score	44.31264 percent	6.19
17	TOF45 Score	0.26772 seconds	0.02929
18	TOF50 Score	0.26993 seconds	0.03203
19	TOF55 Score	0.26603 seconds	0.03088
20	T5F45 Score	0.27695 seconds	0.03049
21	T5F50 Score	0.27262 seconds	0.03099
22	T5F55 Score	0.26965 seconds	0.03042

By considering 1 through 12 as variables to be plotted along the horizontal axis (abscissa) of a graph, and by considering variables 13 through 22 as the variables to be plotted along the vertical axis (ordinate), the obvious questions that arise are (1) what is the correlation between any 2 variables, and (2) what is the linear regression equation for the same 2 variables?

The computer subroutine "REGRE", from the IBM Scientific Package that is in the NPS IBM 360 System, was used to compute the correlation and regression equation for 48 pairs of variables. This program also provided the mean and standard deviation for each of the 22 variables.

By designating the variable to be plotted along the horizontal axis as X, and the variable to be plotted along the vertical axis as Y, the following display shows the information obtained from the Computer Program REGRE:

X	Y	CORRELATION	LINEAR REGRESSION EQUATION
(AGE)			
1	13	0.17422	Y = 0.44643 + 0.00058X
1	14	0.12576	Y = 0.24938 + 0.00026X
1	15	0.10750	Y = 0.19747 + 0.00031X
1	16	-0.03161	Y =44.7809 - 0.01241X
1	17	0.04163	Y = 0.26480 + 0.00008X
1	18	0.08972	Y = 0.26305 + 0.00008X
1	19	0.12513	Y = 0.25678 + 0.00024X
1	20	0.01744	Y = 0.27568 + 0.00003X
1	21	0.09406	Y = 0.26564 + 0.00018X
1	22	0.03488	Y = 0.26711 + 0.00007X
(HEIGHT)			
2	13	-0.23022	Y = 0.74067 - 0.00388X
2	14	-0.08263	Y = 0.32021 - 0.00087X
2	15	-0.20932	Y = 0.42441 - 0.00306X
2	16	-0.14866	Y =65.1743 - 0.29672X
2	17	-0.12869	Y = 0.35316 - 0.00122X
2	18	-0.09820	Y = 0.34121 - 0.00101X
2	19	-0.10300	Y = 0.33810 - 0.00103X
2	20	-0.12201	Y = 0.36127 - 0.00120X
2	21	-0.12597	Y = 0.36110 - 0.00126X
2	22	-0.10615	Y = 0.34282 - 0.00104X
(WEIGHT)			
3	13	0.04419	Y = 0.45065 + 0.00010X
3	14	-0.16083	Y = 0.29906 - 0.00023X
3	15	0.16594	Y = 0.15185 + 0.00033X
3	16	0.21645	Y =34.1158 + 0.05840X
3	17	-0.09157	Y = 0.28813 - 0.00012X
3	18	-0.21162	Y = 0.32150 - 0.00030X
3	19	-0.08409	Y = 0.28578 - 0.00011X
3	20	-0.22693	Y = 0.32960 - 0.00030X
3	21	-0.08613	Y = 0.29292 - 0.00012X
3	22	-0.04680	Y = 0.28048 - 0.00006X

X	Y	CORRELATION	LINEAR REGRESSION EQUATION
(EXPERIENCE)			
4	13	0.05287	Y = 0.46431 + 0.00019X
4	14	0.12880	Y = 0.25328 + 0.00029X
4	15	-0.03321	Y = 0.21127 - 0.00011X
4	16	-0.13836	Y =45.51997 - 0.05999X
4	17	0.02793	Y = 0.26657 + 0.00006X
4	18	0.13463	Y = 0.26385 + 0.00030X
4	19	0.10625	Y = 0.26140 + 0.00023X
4	20	0.04488	Y = 0.27502 + 0.00010X
4	21	0.06739	Y = 0.26967 + 0.00015X
4	22	0.02157	Y = 0.26872 + 0.00005X
5	13	-0.10021	Y = 0.57035 - 0.00289X
6	14	0.20930	Y = 0.09758 + 0.00484X
7	17	0.27307	Y = 0.11468 + 0.00479X
8	18	0.28377	Y = 0.10001 + 0.00524X
9	19	0.27476	Y = 0.08982 + 0.00536X
10	20	0.05046	Y = 0.24592 + 0.00102X
11	21	0.19937	Y = 0.16335 + 0.00358X
12	22	0.16118	Y = 0.17392 + 0.00308X

The linear regression equations for age versus reaction time scores were of interest to the experimenter. AAA scores (variable 13) and NPS Score (variable 14) were plotted on the same graph against age (variable 1). Also on the same graph, the equations obtained from testing 50 subjects at Kansas State University were plotted. See figure 8. The NPS pedal had slightly faster reaction times for its subjects.

The percentage of reaction time saved was computed by dividing the difference between the average AAA and NPS Scores by the average AAA Score. The graph of the percent of reaction time saved (variable 16) and age (variable 1) appears in figure 9.

The distribution of average reaction times was examined for all 55 subjects. For the one-pedal NPS system, the maximum reaction point was 0.3809 seconds, and the minimum was 0.2131 seconds. The range was 0.1678 seconds. For the AAA two-pedal system, the maximum time was 0.6035 seconds, and the minimum was 0.3416 seconds. The range was 0.2619 seconds.

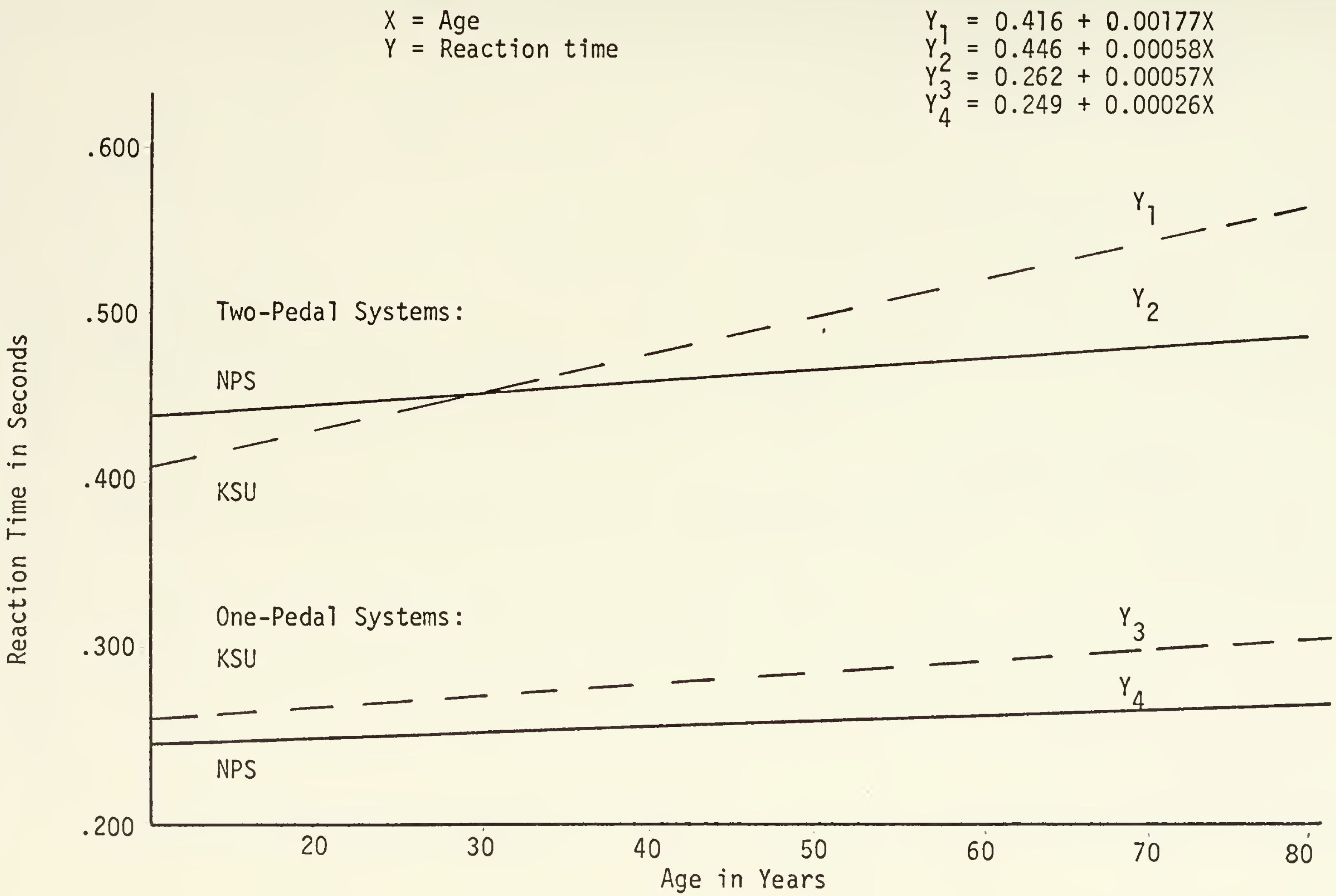

Figure 8. A graph of age versus reaction time using one and two pedals.

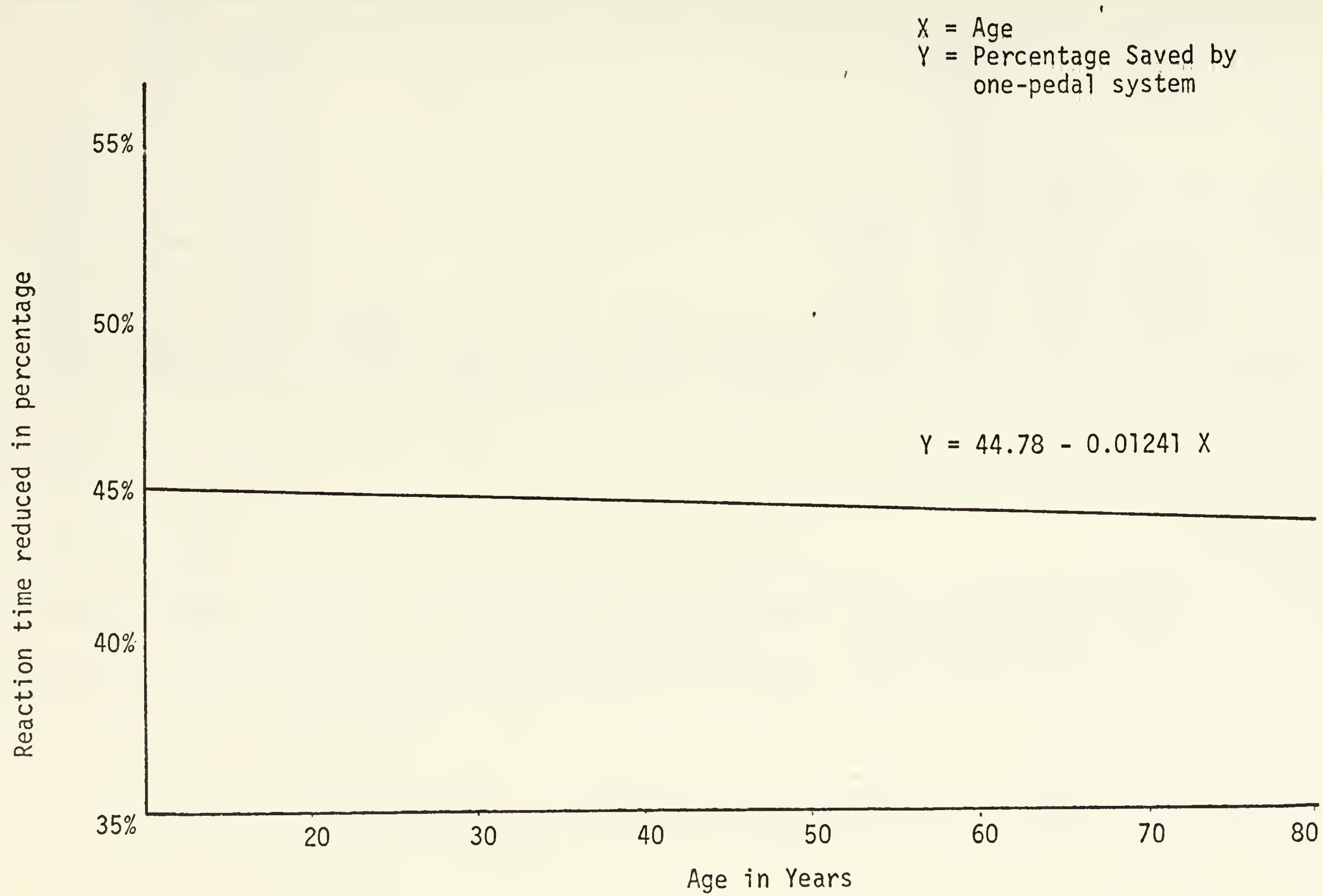

Figure 9. A graph of age versus percentage of reaction time reduced.

REACTION TIMES VS DRIVERS. NEW SYSTEM MEAN IS .260 SECONDS. OLD SYSTEM MEAN IS .470 SECONDS.

```
FREQUENCY     12    18    17     4     2     2     3     2     8    16    11     6     2     2     4     1
----------------------------------------------------------------------------------------------------------
        18        ****
        17        ****  ****
        16        ****  ****                                    ****
        15        ****  ****                                    ****
        14        ****  ****                                    ****
        13        ****  ****                                    ****
        12  ****  ****  ****                                    ****
        11  ****  ****  ****                                    ****  ****
        10  ****  ****  ****                                    ****  ****
         9  ****  ****  ****                                    ****  ****
         8  ****  ****  ****                              ****  ****  ****
         7  ****  ****  ****                              ****  ****  ****
         6  ****  ****  ****                              ****  ****  ****  ****
         5  ****  ****  ****                              ****  ****  ****  ****
         4  ****  ****  ****  ****                        ****  ****  ****  ****              ****
         3  ****  ****  ****  ****              ****      ****  ****  ****  ****              ****
         2  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****
         1  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****  ****
----------------------------------------------------------------------------------------------------------
INTERVAL    0.23  0.26  0.28  0.31  0.33  0.36  0.38  0.41  0.43  0.46  0.48  0.51  0.53  0.56  0.58  0.61
EACH **** EQUALS  1 POINTS
```


The one-pedal system distribution of reaction times was between 0.2131 and 0.3809 seconds.

The two-pedal system distribution of reaction times was between 0.3416 and 0.6035 seconds.

Figure 10. A histogram of 110 average reaction times for 55 subjects who tested both the old, two-pedal system and the new, one-pedal system.

A histogram of these reaction times were obtained by using the computer routine "HISTO". Along the horizontal axis, the variable is time in seconds. The times that appear on the axis are the upper class intervals. The vertical axis shows the number of times that a reaction time occurred in the class interval. There are 110 reaction times plotted on the histogram, 55 NPS times and 55 AAA times. See figure 10.

The distribution of average reaction times on the histogram shows that the NPS reaction times tend to be non-normal. The left or lower tail does not contain enough data points for the distribution to be considered symmetrical. The distribution is skewed to the right.

To verify that these averaged reaction times were not normally distributed, the data was plotted on Normal Probability paper. The data from the NPS system tended to vary from normality more than the AAA two-pedal system. Both distributions were non-normal.

The hypothesis that the mean of the two-pedal system was equal to the mean of the one-pedal system was rejected. This was expected because the mean of the reaction times for the AAA system was 0.470 seconds, but the mean for the NPS system was 0.260 seconds.

The statistical test used to reject the above hypothesis was the Student t-test for matched pairs. Although this test has an assumption that the observations must be normally distributed, the test is considered robust. In this case, this means that the t-test is not sensitive to a violation of normally distributed reaction times. Based on 55 paired observations, the computed t statistic was 34.2. The critical value, at the 5 percent level of significance for a one-tail test, was 2.304. Consequently, the hypothesis that the two means are equal was rejected. This was expected.

The data for the comparison of the two systems was compiled by age group. Then an average reaction time by age group was computed. The breakdown was as follows:

AGE GROUP	AAA AVERAGE	NPS AVERAGE	% SAVED
1) 14-24	0.45021	0.26064	44.0
2) 25-30	0.47336	0.26024	44.9
3) 31-36	0.44984	0.25650	42.7
4) 37-52	0.47827	0.26093	45.5
5) 53-79	0.48731	0.26564	44.5
overall:	0.46820	0.25919	44.3

For this first portion of the experiment, the fastest age group based on average reaction times was age group 3 in both systems. They saved the least percentage, although 42.7 percent is a substantial reduction in reaction time.

The slowest age group was the oldest group in both systems, as was anticipated.

This data provided an indication that reaction time does not have a linear relationship with age. This means that a graph of these two variables would not be a straight line.

In evaluating the effect of seat tilt on reaction time, one of the first steps taken was a check of the distribution of the averaged reaction times. For each of the six treatment combinations of two seat tilts and three floor angles, a histogram was plotted. This information was obtained by using the computer routine "BIMED 07D". The six histograms all showed distributions that were slightly skewed to the right. The 55 test subjects did not have reaction times that were symmetric about the average reaction time.

Using normal probability paper, the distribution of 55 reaction times for each of the 6 treatments were graphed. The data was not normally

distributed. However, the non-normality did not appear severe, and an appeal to the robustness of the F-test was made for further parametric testing that used critical values from the F-distribution.

The parametric technique for testing whether several samples have come from identical populations is the F-test. The assumptions associated with the statistical model underlying the F-test are:

1) The reaction time scores are independently drawn from normally distributed population.
2) The populations have the same variances.
3) The means in the normally distributed population are linear combinations of effects due to seat tilt and pedal angles. (The effects are additive.)
4) The F-test requires Interval Data, such as reaction time.

Suppose the design for comparing six treatments of equal size are matched by comparing the same individuals under all six conditions. For such designs, statistical tests for six related samples should be used. In this experiment, since the data from six matched samples was in at least an ordinal scale, the Friedman 2-way ANOVA by ranks was useful for testing the null hypothesis that the six treatments have been drawn from the same population. In other words, the null hypothesis was that the six treatments had equal means.

The data was cast in 2-way table having 55 rows and 6 columns where rows represent subjects and columns represent combinations of seat tilt and floor angles. Then, one row gave the scores of one subject under the six conditions.

The data for the 2-way Friedman ANOVA test are RANKED scores. The scores in each row are ranked separately. The Friedman test determined whether it was likely that the different columns of rank (samples) came from the same population. If the null hypothesis is true, then the distribution of ranks in each column would be a matter of chance.

The computer subroutine "TWOAV" facilitated the computation of the Friedman statistic. The Friedman chi-square computed statistic was 17.1472. With five degrees of freedom, this observed value was significant at the 1 percent level. Thus, the null hypothesis that there was no difference in the six combinations of seat tilt and floor angle was rejected. The next question to consider was "which treatment or treatments significantly affected reaction time?"

As a preliminary estimate of the answer, seat tilt was considered as the cause for rejection. This estimate was based on the premise that there was no difference in floor angles of the pedal, using reaction time as a criterion. The six averaged reaction times for each subject were reduced by averaging again to obtain just two data points per subject. One data point represented the average reaction time for seat tilt of zero and the other data point represented the average reaction time for a seat tilt of five degrees. For each subject, this means there were 55 paired observations containing only seat-tilt information.

Two statistical tests were utilized in testing the null hypothesis that the mean of the seat-tilt-zero data equalled the mean of the seat-tilt-five-degree data. The first test used was the Wilcoxin Matched Pair Signed Rank test. This nonparametric test <u>accepted</u> the hypothesis at the 10 percent level. The computer subroutine "MPAIR" was used for this computation. The second test used was the t-test for matched pairs. Let us consider for a moment the concept of matched pairs. This process will be extended to a higher dimension subsequently.

In the experiment, several observations were collected on the same test subject. After data reduction, two reaction times per subject remained available for further analysis of the seat-tilt impact on

reaction time. This design is a repeated measurement experiment, whereby each subject serves as his own control in the comparison of a control treatment (seat tilt = 0) and the treatment of interest (seat tilt = 5).

The experimenter felt that it was reasonable to assume that the treatment had an additive effect. This means that the reaction-time responses can be written, for the ith subject, as:

$$X_{i1} = \mu + e_{i1} \qquad \text{(seat tilt 0)}$$
$$X_{i2} = \mu + \tau + e_{i2} \quad \text{(seat tilt 5)}$$

where μ is a general-level effect common to all 55 subjects and treatments, τ is the effect of the experimental condition; e_{i1} and e_{i2} are random disturbance terms.

The essential feature of the design with repeated measurements is that the random disturbances reflect fairly constant characteristics of the ith subject, and THUS MUST BE TREATED AS CORRELATED.

If we assume that the pairs (e_{i1}, e_{i2}) are independently distributed according to a bivariate normal distribution with parameters

$$E(e_{i1}) = E(e_{i2}) = 0$$
$$Var(e_{i1}) = \sigma_1^2$$
$$Var(e_{i2}) = \sigma_2^2$$
$$Covariance(e_{i1},e_{i2}) = \rho\sigma_1\sigma_2 \quad \text{for all subjects,}$$

then we can test the hypothesis that $\tau = 0$ by using the sample information. By taking the differences between treatment and control, we find t using $t = \overline{d}\sqrt{N}/S_d$, where

$\overline{d}$ = the mean of the differences between treatment and control data,

S_d = the standard deviation of these differences, and

N = 55 = the sample size.

If the hypothesis is true, t has the Student t distribution with (N - 1) = 54 degrees of freedom.

The results of this second test of the hypothesis that the two seat-tilt means are equal was that the hypothesis was accepted, even at the 10 percent level. Since the Wilcoxin and the t test accepted the equal mean reaction time hypothesis based on seat tilt, and since results of the Friedman Two-Way Analysis of Variance test indicated at least one of the six treatment means was not the same, the issue was still unresolved.

The main design that was planned for the analysis of the experiment was a three-way analysis of variance design. The three factors involved were two levels of seat tilt, three levels of floor angle, and five levels of age groups of test subjects. The critical values are based on the F-ratio or F distribution whose assumptions were listed previously.

Since each subject was observed under each of the six combinations of seat-tilt and floor-angle treatments, the experimental design involved repeated measurements on two of the three factors. This means that data for six treatments were related to one person. The reaction times are not independent. "Repeated measures" refers to the fact that for each of the eleven persons in an age group, the experiment was repeated using one test subject for six treatments.

The impact of repeated measurements on test subjects is that one cannot use the full-factorial analysis of variance designs. This experimenter used the three-factorial experiment with repeated observations on the last two factors, as described by Winer (1962). Although they are factorial designs, computer programs BIMED 02V and 08V were helpful in compiling the following table, which was completed by hand calculations:

Source	DF	SS	MS	Fcalculated	Fcrit
A	4	.0236574	.0059143	1.2984763	3.74
error(a)	50	.2277403	.0045548		
B	1	.0022147	.0022147	9.9761261**	7.19
AB	4	.0003515	.0000878	.3954954	3.74
error(b)	50	.0111038	.0002220		
C	2	.0012166	.0006083	2.8558685	4.89
AC	8	.0007731	.0000966	.45352	2.74
error(c)	100	.0213003	.000213003		
BC	2	.0006885	.0003442	1.7871235	4.89
ABC	8	.0012056	.0001507	.7824506	2.74
error(bc)	100	.0191259	.0001926		
TOTAL	329	.3093777			

** Significant at the 1% level.

The hypothesis that was tested was that the levels under each factor had equal means. The only hypothesis that was rejected was the main effect B hypothesis that both levels of seat tilt had equal mean reaction times. The mean reaction times for the two levels of seat tilts, based on the information from BIMED 02V were:

B1 (tilt 0): 0.26789 seconds
B2 (tilt 5): 0.27307 seconds.

The conclusion is that there is a statistically significant difference in seat tilts using reaction time as a criterion, at the 1 percent level of significance. The effect of seat tilt of 5 degrees is to increase reaction time. However, these results were not clear.

The assumptions necessary for using these results include linearity and homogeneous variances. The Bartlett test, the Cochran test, and Hartley's F-Max test were all used to check the hypothesis that the variances of the data were homogeneous. All tests accepted this hypothesis. This meant that the assumption of equal variances in the population was satisfied.

However, the assumption of linearity was not satisfied. Part of the computer printout from the program BIMED 02V includes a breakdown of the sum of squares orthogonal components for each of the three factors. The seat-tilt factor and the floor-angle factor were essentially linear, but the age-group factor was <u>not</u> linear. The sum-of-squares term for age groups had orthogonal components that were 14 percent linear, 20 percent quadratic, 39 percent cubic, and 27 percent higher order. This was significantly non-linear overall.

Nonlinearity complicated the results of the three-way Anova. The implication that both seat tilts were different for all floor angles seemed also inconsistent by looking at the data from the "REGRE" PROGRAM (Variables 17 through 22):

TREATMENT	SAMPLE MEAN	RANK
T0F45	0.26772 seconds	2
T0F50	0.26993 seconds	4
T0F55	0.26603 seconds	1
T5F45	0.27695 seconds	6
T5F50	0.27262 seconds	5
T5F55	0.26965 seconds	3

The largest sample mean was the treatment mean for the five-degree seat tilt and the 45-degree floor angle on the NPS pedal. The smallest sample mean occurred for the horizontal seat at the 55-degree floor angle on the pedal. The three fastest reaction time means included the treatment T5F55 which had a seat tilt of 5 degrees. This cast some doubt on the conclusion that seat tilt increased reaction time for all three pedal angles. The sample mean for T5F55 was faster than the sample mean for T0F50. To resolve the issue, the data processing included a multivariate approach, which is the analogue of the Friedman 2-Way ANOVA.

When the Friedman Two-Way Analysis was used to test the hypothesis that the six treatment means were equal, the conclusion was that they were not the same. However, there is no technique known to this experimenter to process that data to isolate the treatment or treatments that cause those findings by using distribution-free statistical tests. However, the same hypothesis can be tested using the assumption that the six observations per person, repeated 55 times, constituted a random sample from a Multivariate Normal distribution.

The literature refers to the Hotelling T-squared test statistic for testing this hypothesis that the six treatments are the same. The T^2 statistic requires no assumption about homogeneity of covariances, but is more complex computationally. The issue to be resolved was essentially a problem of symmetry. In multivariate analysis, the Hotelling T^2 Statistic helps to determine if all the treatment means are equal to one another. A description of the multivariate approach follows.

Related observations from a repeated-measurements experiment is an extension of the paired-observations case to the general set up of k-responses on the same subject under a variety of experimental conditions. Here k = 6, the number of averaged reaction times given by each test subject.

The six responses constituted a fixed set in the sense that the inferences about their parameters will apply only to the particular responses investigated in this experiment: seat tilts of zero and 5 degrees, and pedal-floor angles of 45, 50, and 55 degrees. Let:

N = 55; the number of test subjects,
k = 1, 55; a particular subject, and
j = 1, 6; one of the six treatments.

The math model for the jth response of the ith test subject is:

$$X_{ij} = \mu + \mu_j + e_{ij}$$

where

μ = general level parameter common to all observations,

μ_j = measure of effect specific to the jth condition, and

e_{ij} = random disturbance.

The variate e_{ij} reflects both the intersection of the ith subject with the jth response, and the experimental error in that conjunction. It is necessary here to assume that the vector of variates, called a "residual vector," $(e_{i1},e_{i2},e_{i3},e_{i4},e_{i5},e_{i6})$ of the ith person, has the multivariate normal distribution with

$$\text{mean vector} = E(e_{i1},\cdots,e_{i6}) = (0,0,0,0,0,0)$$

and

$$\text{Covariance Matrix} = \Sigma = E\left(\begin{bmatrix} e_{i1} \\ e_{i2} \\ e_{i3} \\ e_{i4} \\ e_{i5} \\ e_{i6} \end{bmatrix} \cdot [e_{i1},e_{i2},e_{i3},e_{i4},e_{i5},e_{i6}]\right).$$

The null hypothesis of equal response effects on reaction time is:

H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$

H_1: For at least one pair of 6 distinct treatments, two means are not equal.

The vector statements of these hypotheses are:

$$H_o: \begin{bmatrix} \mu_1 - \mu_2 \\ \mu_2 - \mu_3 \\ \mu_3 - \mu_4 \\ \mu_4 - \mu_5 \\ \mu_5 - \mu_6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad \text{and } H_1: \begin{bmatrix} \mu_1 - \mu_2 \\ \mu_2 - \mu_3 \\ \mu_3 - \mu_4 \\ \mu_4 - \mu_5 \\ \mu_5 - \mu_6 \end{bmatrix} \neq \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

The test of the null hypothesis can be carried out by the use of the Hotelling T^2 statistic:

$$T^2 = N\overline{X}^T C^T (CSC^T)^{-1} C\overline{X}$$

where $N = 55$ = Sample size,

$\overline{X}$ = vector of six sample means,

S = the sample covariance matrix

C = the $(k-1)X(k)$ patterned matrix which yields differences of observation on adjacent reaction-time responses.

If the null hypothesis is true, then

$$F = \frac{N - k + 1}{(N-1)(k-1)} T^2$$

has the F-distribution with $(k-1) = 5$ and $(N-k+1) = 50$ degrees of freedom.

If the level of significance of the test is α, the null hypothesis is rejected when $F \geq F_{\alpha}$; 5, 50. Otherwise, accept H_0, the null hypothesis.

In this experiment, the critical values for F are:

LEVEL	F
10%	1.975
5%	2.410
1%	3.420

The multivariate analysis of repeated measurements is shown in the following steps:

1. Ordered treatment means were:

$$\begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \\ \mu_6 \end{bmatrix} = \mu = \begin{bmatrix} \text{T0F45} \\ \text{T0F50} \\ \text{T0F55} \\ \text{T0F45} \\ \text{T5F50} \\ \text{T5F55} \end{bmatrix} \text{ where } \bar{x} = \begin{bmatrix} 26.7721 \\ 26.9926 \\ 26.6024 \\ 27.6952 \\ 27.2615 \\ 26.9648 \end{bmatrix}$$

2. S was obtained from BIMED 02D where S = the Sample Variance-Covariance Matrix:

$$\begin{bmatrix} 8.5812 & 6.9182 & 7.3497 & 6.5251 & 7.3279 & 7.0588 \\ 6.9182 & 10.2593 & 8.3375 & 7.2129 & 7.7136 & 7.7642 \\ 7.3497 & 8.3375 & 9.5357 & 6.8308 & 8.0785 & 8.1388 \\ 6.5251 & 7.2129 & 6.8308 & 9.2978 & 7.2482 & 7.2538 \\ 7.3279 & 7.7136 & 8.0785 & 7.2482 & 9.6053 & 7.6418 \\ 7.0588 & 7.7642 & 8.1388 & 7.2538 & 7.6418 & 9.2525 \end{bmatrix}$$

3. C was a matrix defined to give contrasts between tilts, between largest and smallest sample means, and between second largest and smallest sample means:

$$C = \begin{bmatrix} -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & -1 & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 0 & 0 & 1 \\ 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 1 & 0 \end{bmatrix} \text{ and } C^T = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & -1 & -1 & -1 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

4.

$$C\overline{X} = \begin{bmatrix} \text{T5F45} - \text{T0F45} \\ \text{T5F50} - \text{T0F50} \\ \text{T5F55} - \text{T0F55} \\ \text{T5F45} - \text{T0F55} \\ \text{T5F50} - \text{T0F55} \end{bmatrix} = \begin{bmatrix} 0.9231 \\ 0.2689 \\ 0.3624 \\ 1.0928 \\ 0.6591 \end{bmatrix}$$

5. $\overline{X}^T C^T = (0.9231, 0.2689, 0.3624, 1.0928, 0.6591)$.

6.

$$CSC^T = \begin{bmatrix} 4.8288 & -0.3744 & 0.7139 & 3.2916 & 0.4392 \\ -0.3744 & 4.4374 & 0.1366 & 0.2943 & 2.1507 \\ 0.7139 & 0.1366 & 2.5106 & 1.8199 & 0.9602 \\ 3.2916 & 0.2943 & 1.8199 & 5.1719 & 1.8746 \\ 0.4392 & 2.1507 & 0.9602 & 1.8746 & 3.0840 \end{bmatrix}$$

7. $(CSC^T)^{-1}$ is obtained from GAUSS 3 program:

$$(CSC^T)^{-1} = \begin{bmatrix} 0.4114 & -0.0056 & 0.0770 & -0.3339 & 0.1240 \\ -0.0056 & 0.3765 & 0.0446 & 0.0851 & -0.3274 \\ 0.0779 & 0.0446 & 0.5659 & -0.2207 & -0.0842 \\ -0.3339 & 0.0851 & -0.2207 & 0.5875 & -0.3002 \\ 0.1240 & -0.3274 & -0.0842 & -0.3002 & 0.7436 \end{bmatrix}$$

8. $T^2 = N\overline{X}C^T(CSC^T)^{-1}(C\overline{X})$.

9. $T^2 = 16.4194195$.

10. $F = (5/27)T^2 = 3.0406332$.

Therefore, the null hypothesis is rejected at both the 10 percent and the 5 percent levels, but not at the 1 percent level.

Since the hypothesis of equal treatment effects for all six settings of seat tilt and floor angle is rejected, this means that at least one pair of treatments did not have equal means.

Simultaneous confidence limits can be used to determine which of the treatments differ. This multiple comparison of pairs is an extension of the Scheffe´ Technique to repeated-measurement designs. An examination of the formula

$$F = \frac{N-k+1}{(N-1)(k-1)} T^2$$

yields the following formula for T:

$$T = \sqrt{\frac{(N-1)(k-1)}{(N-k+1)} F} \ .$$

Then:

LEVEL	F	T
10%	1.975	3.2657312
5%	2.41	3.6074922
1%	3.42	4.2974410

For one simultaneous confidence interval for a contrast, say $\mu_B - \mu_A$, the 100(1 - α) percent confidence limit can be written as $(L \leq \mu_B - \mu_A \leq U)$ where L is the lower limit and U is the upper limit. If the interval includes zero, then one can accept the hypothesis that $\mu_B = \mu_A$.

In this analysis, simultaneous confidence limits were used to isolate which pair or pairs of treatment means caused rejection of the null hypothesis in the Hotelling T-squared test (and the Friedman Two Way ANOVA test). The level of significance was set at 10 percent. (See Morrison, page 139.)

1) $Pr(-0.0445505 \leq \mu_4 - \mu_1 \leq 1.8907505) = 90\%$ (accept H_o)

2) $Pr(-0.6587064 \leq \mu_5 - \mu_2 \leq 1.1965064) = 90\%$ (accept H_o)

3) $Pr(-0.3353316 \leq \mu_6 - \mu_3 \leq 1.0601316) = 90\%$ (accept H_o)

4) $Pr(-2.0942304 \leq \mu_4 - \mu_3 \leq -0.0913616) = 90\%$ (reject H_o)*

5) $Pr(-0.1142143 \leq \mu_5 - \mu_3 \leq 1.4324143) = 90\%$ (accept H_o)

* The only significant comparison at the 10 percent level is that treatment mean 3 does not equal treatment mean 4. The implication is that the

treatment with seat-tilt zero and pedal-angle 55 degrees is different from the treatment with seat-tilt 5 degrees and pedal-angle 45 degrees. The only statistically significant pair that caused rejection of both Hotelling and Friedman tests was the pair containing the minimum and maximum treatment means.

After the comparison of reaction times from the two-pedal and one-pedal systems, and the isolation of the seat tilt-floor angle combination that significantly affected reaction time, the remaining data to be processed concerned ranks.

For each test subject there were three sets of ranks. From the experiment, each test subject provided ten data points in each of six combinations of seat-tilt and pedal-floor angles. These ten data points were averaged and ordered. A rank of one was given the fastest time (smallest), and a rank of six was given the slowest time (largest).

These six ranked times were compared with six ranks also provided by the test subject who ranked the six combinations of seat and pedal angles using comfort as a criterion.

RS (Spearman Rank Correlation Coefficient) was computed for each treatment combination using ranked times and ranked comfort for each subject as data points.

The sequence that each subject experienced the six treatments also provided a set of "ranks" for each subject. These sets were numbers one through six. They could be compared directly with both the ranks for comfort and the ranks by time available for each test subject.

The Spearman Rank Correlation Coefficients (RS) between the rank by comfort and the rank by time, the rank by comfort and sequence, and the rank by time and sequence were measures of association that provided more information to the experimenter. Here, the sample size was N = 55.

When the sample size is greater than ten, the significance of an obtained RS may be tested by the statistic

$$t = RS\sqrt{\frac{N - 2}{1 - RS^2}} \; .$$

The critical value was obtained from the Student-t distribution with (N - 2) 53 degrees of freedom.

The computations of three RS coefficients for each of the six treatments were performed by using the computer programs "SRANK," "RANK," and "TIE." The computer output, which included the computed value for t, is summarized in the following:

TREATMENT	(a) RS	(b) RS	(c) RS
TOF45	0.232	0.000279	0.108
TOF50	0.075	-0.1858	0.059
TOF55	0.120	-0.00146	-0.182
T5F45	0.232	-0.09766	0.354
T5F50	0.202	-0.33110	-0.077
T5F55	0.176	-0.10528	-0.018

Legend:

(a): correlation between the rank by comfort and rank by time,
(b): correlation between rank by comfort and sequence, and
(c): correlation between the rank by time and sequence.

The computed values of t, where $t = RS\sqrt{\frac{53}{1 - RS^2}}$, for each treatment and for each of three pairs are as follows:

TREATMENT	(a) t	(b) t	(c) t
TOF45	1.73*	0.0020	0.790
TOF50	0.54	-1.370	0.430
TOF55	0.88	-0.010	-1.350
T5F45	1.73*	-0.710	2.760***
T5F50	1.49	-2.50**	-0.560
T5F55	1.30	-0.77	-0.136

where (a), (b), and (c) are the same paired ranks explained by the previous legend.

The hypothesis being tested is that RS $\leq$ 0 in the population, and that the observed value of RS differs from zero only by chance. The critical value of t at the 5 percent level and 53 degrees of freedom is t = 1.645. The results indicate:

For (a), accept H_0* except for RS at T0F45 and T5F45.

For (b), accept H_0** except for RS at T5F50.

For (c), accept H_0*** except for RS at T5F45.

The implication is that there was practically no association between ranks by comfort, ranks by time, or the sequence in which each test subject experienced the six treatments.

There is a way to express the degree of association among the 55 sets of rankings by comfort of the 6 treatments provided by the test subjects. The statistic used is W and is called the Kendall Coefficient of Concordance. Usually, W is greater than zero and less than one. Using the computer programs "WTEST," "RANK," AND "TIE," the W statistic was computed. In this case, W = 0.0657. It was not significantly different from zero. This suggests that there was no practical association among the 55 subjects as to the most comfortable combination of seat tilt and pedal angle.

VI. RESULTS

Based on 55 subjects from age 14 to age 79, the results of the experiment showed that the NPGS, one-pedal, dual-function system saved an average of 44 percent in reaction time over the AAA, two-pedal system. With one exception, the effect of a 5 degree seat tilt on reaction time was not statistically significant at the ten percent level, when the pedal-floor angle was 45, 50, or 55 degrees. The one exception was the combination of seat tilt at 5 degrees and floor angle at 45 degrees. This was significantly different. The mean reaction time was slower at that combination compared with the mean reaction times of the other five combinations.

In the two-pedal (conventional) AAA portion of the experiment, the fastest average reaction time for ten recorded trials after ten warmups by an individual was 0.3416 seconds. This time came from a 57-year-old state park attendant who was 77 inches tall. He weighed 180 pounds. He drove a 1962 automobile, equipped with automatic transmission. He had been driving for about 40 years without an accident. The slowest average reaction time by an individual was 0.6035 seconds. This participant was a 62-year-old professor. The mean reaction time for all subjects on the AAA two-pedal machine was 0.46820 seconds.

The one-pedal device, which was set at a 60-degree floor angle with no rotational angle, functioned significantly better than the two-pedal device at the same floor and rotational angle. The mean reaction time for all subjects on the one-pedal device was 0.25919 seconds. The fastest average reaction time in ten trials after ten warmups by a test subject in this new system was 0.2131 seconds.

The fastest average reaction times in both systems were achieved by different test subjects, although the same 55 subjects participated throughout the experiment. On the NPS device with the same settings as the AAA machine, the best performer was a 45-year-old security guard at the Naval Postgraduate School. He was 72 inches tall, weighed 212 pounds, drove an automobile equipped with automatic transmission, and had been driving for 25 years. The slowest reaction time on the NPS device was a 0.3809 seconds. This subject was a 30-year-old jet pilot whose average reaction time on the AAA device was 0.5726 seconds.

For the seat-tilt portion of the experiment, which always followed the comparison of the AAA and NPS systems, the results are discussed in terms of average reaction times for age groups, for seat tilts, and for floor angles. These reaction times were obtained when the pedal rotation was fixed at a ten-degree angle to the right of center. The pedal-floor angles were either 45, 50 or 55 degrees. The seat-tilt angle was either zero or five degrees above the floor measured at the front edge of the seat.

There were eleven subjects in each age group. The mean reaction times by age group, regardless of seat tilt or pedal angle were:

GROUP	AGES	MEAN REACTION TIME (SECONDS)	RANK
1	14-24	0.25646	1
2	25-30	0.28255	5
3	31-36	0.26798	2
4	37-54	0.27266	3
5	55-79	0.27276	4

The group with the fastest mean reaction time included four high school students, a 20-year-old State Park employee, four newly commissioned officers working on master degrees, and two officer instructors.

Age group two had the slowest mean reaction time for all combinations of floor and seat angles. The fact that the oldest age group was not the slowest group is remarkable.

With no tilt on the seat, that is, a seat tilt which is horizontal, the mean reaction time for all test subjects over all three floor angles was 0.26789 seconds. When the front edge of the seat was raised so that the seat had a 5 degree tilt, the mean reaction time for all 55 subjects over all floor angles was 0.27307 seconds. This slight increase in time was not statistically significant at the 1 percent level when the t-test for matched pairs was used.

The mean reaction times at each floor angle position for all subjects regardless of seat tilt was as follows:

PEDAL ANGLE ABOVE THE FLOOR	MEAN REACTION TIME	RANK
45 degrees	0.27234 seconds	3
50 degrees	0.27127 seconds	2
55 degrees	0.26784 seconds	1

The 55 degree floor angle had the fastest mean reaction time, although the differences are in thousandths of a second. Little practical difference exists among these averages.

By considering a combination of floor angle and seat-tilt angle as a treatment, the same 55 test subjects experienced 6 treatments. The combination of 5-degree seat tilt and 45-degree pedal-floor angle was a treatment that was statistically significantly different from the other 5 treatments. The results by treatment are shown below:

TREATMENT	MEAN REACTION TIME	FASTEST	SLOWEST
T0F45	0.26772	0.21700	0.36460
T0F50	0.26993	0.21440	0.36690
T0F55	0.26603	0.20200	0.36860
T5F45	0.27695	0.20900	0.38960
T5F50	0.27262	0.21880	0.38050
T5F55	0.26965	0.22260	0.37430

For five of the six treatments, the person with the fastest average reaction time in ten trials after ten warmups was a 50-year-old security guard at the NPS. He was 72 inches tall, weighed 200 pounds and had been licensed only 18 years. He was the fastest performer, except for the treatment with seat tilt=zero and floor angle=55 degrees. In the latter case, the person with the best average time was a 23-year-old Marine Second Lieutenant, an Infantry Officer, who was 67 inches tall and weighed 145 pounds.

For five of the six treatments, the test subject with the slowest average reaction time in ten trials after ten warmups in every treatment combination was a 30-year-old jet pilot. He was 70 inches tall and weighed 176 pounds. For the treatment of seat tilt=zero and pedal-floor angle=55 degrees, the slowest performer after ten warmups and ten trials was a 37-year-old Marine Infantry Officer who was 69 inches tall and weighed 168 pounds.

Under each treatment, the average reaction times were sorted by age group with eleven test subjects in each age group. This sorting of the data created 30 "cells" containing 11 data points each. The mean reaction time by age group under each treatment provided 30 cell means for purposes of comparison. An examination of the cell means showed that the fastest cell mean reaction time was 0.24977 seconds which was based on recorded data from the youngest age group when the seat was horizontal and the pedal angle was 55 degrees. The slowest cell mean reaction time came from the group containing ages 25 to 30 when the seat was tilted 5 degrees and the pedal floor angle was 50 degrees.

All 55 subjects ranked the 6 treatments of pedal and seat combinations in terms of comfort. The experimenter ranked the average reaction time of

each subject for each treatment. When the ranks by comfort were compared to the ranks by reaction time, there was no practical or statistical correlation.

The ranks of the treatments by comfort were compared for all 55 test subjects to ascertain association of ranks. No practical or statistical degree of association among the 6 combinations of seat tilt and floor angle experienced by the 55 test subjects existed.

VII. DISCUSSION

The results indicate that the 55 subjects who participated in the experiment reduced their reaction time by more than 44 percent. The actual time saved averaged over 0.2 seconds. In terms of distance, a savings of 0.21 seconds when a vehicle is traveling at a constant 60 MPH represents a saved distance of 18.48 feet, or about one car length. This "extra" time represents a safety margin that is not found in motor vehicles with a two-pedal system. This safety margin allows time and room for stopping a vehicle, for reducing the speed and thereby lessening the severeity of an accident, or for turning from the path of danger.

The transition from a two-pedal system to a one-pedal system was easily accomplished by the 55 male participants. With 10 warmups before each new treatment, each subject had 140 opportunities to react in a simulated panic situation with the new pedal system. The transition was accomplished quickly, but some minor adjustments were required. For example, one subject stated that he rarely put his entire foot on the gas pedal while driving his car. In this experiment, that subject had to concentrate on placing his entire foot on the dual-function pedal to activate the brake properly.

A question arises about the transition women would experience if they were wearing elevated shoes as opposed to low-heeled or tennis shoes. The pedal angle with the floor, combined with a seat tilt and/or the angle of twist on the pedal might be limited for various heel heights on a woman's shoe.

The amount of reaction time saved compared favorably with similar results obtained at Kansas State University. There are minor differences

in the area of reaction times versus age. These differences could be a function of the test subjects used in the sample. Minor differences could be attributed to occupations. The reaction time of military personnel could differ from that of the civilian community.

There is a related question in this area of reaction time and age. It is intuitively appealing to assume that a youth's reaction time improves with age until the mid-twenties, at which time his reaction time declines with age. This suggests that reaction time is not linear over time. In terms of experimental work with one and two pedal automotive systems, the recorded reaction time also includes co-ordination, practice, experience, and other factors. An older person with good reactions may have poor co-ordination but years of practice. The point is that recorded elapsed times contain factors other than reaction times. The linearity of this data is questionable.

The seat-tilt angles investigated in this experiment were zero and plus five degrees with respect to the horizontal. The 55 test subjects acted as their own control by participating in simulated panic situations at both seat-tilt angles when the angle between the floor and the pedal was 45, 50, or 55 degrees. Using the same subjects was an economic measure in terms of number of subjects and time available.

The results showed that for these 55 subjects, no statistically significant difference in mean reaction time existed, except for one combination. At the 5-degree seat tilt and 45-degree pedal angle, the mean reaction time was significantly greater than the other 5 combinations.

When the seat was tilted at 5 degrees and the pedal was at 45 degrees, test subjects moved their seat as far forward as possible in many cases. This was particularly true for shorter people. Perhaps the strain on the leg muscles at this combination was too great. The combination might

have been awkward for them. One consideration would be to extend the seat runners to allow more lattitude in seat reference distance. Another consideration would be to reduce the seat height. In this experiment it was fixed at 17 inches above the base platform. The vertical height between the front edge of the seat and the heel of the pedal at a 45 degree floor angle was 11.5 inches.

By comparing mean reaction times by age groups at specified combinations of pedal and floor angle, the results of this experiment are compatible with the previous experiments of Toben and West and the Naval Postgraduate School. In all these experiments, the essential equipment was the same. See figure 11.

In general, the results of this experiment were within the range of reaction time averages obtained by West and Toben. The audible click when the light was turned on was not heard in this experiment, as it was in West's experiment. This lack of warning could account for some of the differences in reaction time. The length of time the test subject spent participating in the experiment was only 12 minutes for West compared to 30 minutes for both Toben and Sullivan. A fatigue factor might account for some of the time differential.

Whenever several observations are made on test subjects for different treatments, that is several combinations of seat tilt and floor angle, the statistical design must use a repeated-measures analysis, as opposed to an independent analysis. For example, if the reaction times from the 55 test subjects were assumed to be independent for each treatment, then an incorrect conclusion from an analysis of variance design for three factors would result. The conclusion would be that no difference among the six combinations of seat tilt and floor angle. This was not the case.

SULLIVAN DATA BY AGE GROUPS

GROUP	AGES	# PEOPLE	To F45	To F55
1	14-24	11	0.25250	0.24977
2	25-30	11	0.28108	0.27481
3	31-36	11	0.26735	0.26564
4	37-52	11	0.26924	0.27113
5	53-79	11	0.26843	0.26878

TOBEN DATA BY AGE GROUPS

GROUP	AGES	# PEOPLE	Ro F45	R15F55
1	18-24	9	0.33728	0.32331
2	25-30	9	0.28627	0.27567
3	31-36	9	0.30739	0.29350
4	37-52	9	0.29878	0.28947

WEST DATA BY AGE GROUPS

GROUP	AGES	# PEOPLE	P2F45	P2F60
1	25-30	29	0.22092	0.22140
2	31-36	16	0.22767	0.22456

Legend: T = seat-tilt angle

F = pedal-floor angle

R = pedal-rotation angle

P_2 = pedal type solid (as opposed to hinged).

Figure 11. A summary of selected age group average reaction times for various treatments from experiments performed at NPS in the last year.

Concerning the ranks by comfort and the ranks by time, the meaning of no common association to the experimenter was that the 55 test subjects did not consider the fastest combination to be the most comfortable. The treatments were difficult to distinguish in terms of either time or comfort.

IX. CONCLUSIONS

The single pedal which performed two functions in an automatic system reduced the average reaction time of 55 test subjects by more than 44 percent, when compared to the conventional system. This reduction in reaction time is attributable directly to the time saved by not moving the foot from the accelerator to the brake pedal.

The effect of a 5 degree seat-tilt on reaction time for 55 male subjects from age 14 to 79 was not statistically significant for a pedal-floor angle of 50 or 55 degrees. However, there was statistical significance when the dual-function pedal was 45 degrees above the floor. This occurred when the angle of twist on the pedal was fixed at 10 degrees to the right, and the seat was 11.5 inches above the dual-function pedal.

While the seat tilt for one combination of floor and rotational angles was statistically significant in terms of increased reaction time, the practical significance is not considered to be severe. A designer who used the Naval Postgraduate School pedal could increase the range of seat adjustment by lengthening the seat runners. With this adjustment, the effect on reaction time at pedal angles of 45, 50, or 55 degrees should not be significant for a seat tilt of 5 degrees.

X. RECOMMENDATIONS

The experiment with the single pedal that performs both the acceleration and braking functions was the third experiment at the Naval Postgraduate School. The test subjects have been males from age 14 through age 79, with a majority from the military community, particularly from the officer corps. No test subject received monetary compensation as a motivation factor. Several extensions of this research could include testing with subjects who were paid, who were all enlisted, who were all civilians, or who were all female. The safety aspects of women's shoes with heels of various heights and widths could also be evaluated. It is also suggested that a different subject be used for each treatment rather than repeated measures on the same subject.

The main emphasis of future testing should be in the placement of the single-pedal system in a moving vehicle. The mechanical linkage for accelerating and braking with a single pedal could be designed by people from the military community and with the resources available at the Naval Postgraduate School.

The test vehicles could be extended to include commercial sedans, trucks, jeeps, construction equipment, tracked vehicles, and vehicles that tow aircraft. If the government specified the single-pedal system in its military contracts, the value of the system might become more apparent to the automotive industry and to the public.

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13. ABSTRACT

A total of 55 test subjects from age 14 to age 79 contributed 4400 recorded reaction times in a controlled experiment in the Human Factors Laboratory of the Operations Research Department at the Naval Postgraduate School. One purpose of the experiment was to compare the conventional brake and accelerator system to a new, dual-function, single-pedal system that was developed at the school. A second purpose was to investigate the effect on reaction time of a five degree seat tilt at pedal-floor angles of 45, 50, and 55 degrees with this new pedal.

The average reaction time saved by the single-pedal system was more than 44 percent. The average reaction time on the conventional two-pedal system was 0.46820 seconds compared to 0.25919 seconds for the new one-pedal system. Seat tilt affected reaction time only at the 45 degree angle.

In terms of distance, a savings of 0.20901 seconds for a vehicle traveling at 60 MPH represents a saved distance of 18.39 feet, or about one car length. This margin of safety is not currently available in commercial or military vehicles.

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	ROLE	WT	ROLE	WT	ROLE	WT
eaction Time Reduction						
ingle-Pedal, Dual-Function System						
ne-Pedal Automobile Control						
ncreased Margin of Safety						
ombined Brake-Accelerator Pedal						
wo-Pedal Automotive System						
ne-Pedal Automotive System						
anic Stops -						
ccident Facts by Age Groups						
eaction Time by Age Groups						
eat-Tilt Angles						
edal-Floor Angles						
edal-Twist Angles						
eaction-Time Distributions						
eat Reference Distance						

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c.1 An analysis of the reduction in reaction time and of the effect of seat tilt in a single-pedal automotive system.